NATIONAL BUREAU OF STANDARDS REPORT

4157

PERFORMANCE OF THE FARR ROTONAMIC AIR CLEANER

by

C. W. Coblentz
T. W. Watson
P. R. Achenbach

Report to
Engineering and Development Branch
Office of the Chief of Transportation
Department of the Army
Washington, D. C.

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section is engaged in specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant reports and publications, appears on the inside of the back cover of this report.

Electricity and Electronics. Resistance and Reactance. Electron Tubes. Electrical Instruments. Magnetic Measurements. Process Technology. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.

Heat and Power. Temperature Measurements. Thermodynamics. Cryogenic Physics. Engines and Lubrication. Engine Fuels.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Nuclear Physics. Radioactivity. X-rays. Betatron. Nucleonic Instrumentation. Radiological Equipment. AEC Radiation Instruments.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Gas Chemistry. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Organic Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion.

Mineral Products. Porcelain and Pottery. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Heating and Air Conditioning. Floor, Roof, and Wall Coverings. Codes and Specifications.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. Components and Techniques. Digital Circuitry. Digital Systems. Analogue Systems.

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services.

Radio Propagation Engineering. Frequency Utilization Research. Tropospheric Propagation Research.

Radio Standards. High Frequency Standards. Microwave Standards.

- Office of Basic Instrumentation
- Office of Weights and Measures

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT		NBS REPORT
1003-20-4838	June 16, 1955	4157

PERFORMANCE OF THE FARR ROTONAMIC AIR CLEANER

by

C. W. Coblentz
T. W. Watson
P. R. Achenbach

Heating and Air Conditioning Section
Building Technology Division

To

Engineering and Development Branch
Office of the Chief of Transportation
Department of the Army
Washington, D. C.

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

PERFORMANCE OF THE FARR ROTONAMIC AIR CLEANER

by

C. W. Coblentz, T. W. Watson and P. R. Achenbach

Abstract

The air cleaning efficiency and the pressure drop of a specimen Rotonamic air cleaner manufactured by the Farr Company were determined using a half-and-half mixture of coarse and fine test dust furnished by the A. C. Spark Plug Division of General Motors, Corp. The specimen was comprised of nine cyclones and was tested over a range of air flow rate from 50 to 280 cfm. Efficiency measurements were made simultaneously by the gravimetric and dust-spot methods. Different numerical values of efficiency were obtained by the two methods and the reason for the difference is explained. The gravimetric efficiency ranged from about 70 percent at an air flow rate of 50 cfm to about 94 percent at an air flow rate of 280 cfm. The pressure drop across the air cleaner ranged from 0.63 in W. G. to 16.9 in W. G. over the same range of air flow rate. The gravimetric efficiency was affected only slightly by the rate of bleed-off of dust-laden air in the range from 7 1/2 to 15 percent of the filtered air flow rate. A microscopic examination of the filtered air showed that the air cleaner removed nearly all of the particles larger than three microns in diameter. The important advantages of the Rotonamic air cleaner are that it requires no cleaning, oiling, or servicing and its efficiency remains constant indefinitely for any given duty. The principal disadvantage of the device is the magnitude of its pressure drop. It appears likely, however, that the Rotonamic air cleaner can be applied to helicopters without exceeding the three percent total power loss usually considered as a maximum that can be permitted as a result of applying an air cleaning system.

1. INTRODUCTION

As a part of the research project "Air Filter Systems for Army Aircraft" the performance characteristics of a Rotonamic air cleaner manufactured by the Farr Company were determined with a view to employing this type of filter as an induction air cleaner for helicopter or other small aircraft engines.

2. DESCRIPTION OF TEST SPECIMEN

The test specimen was manufactured by the Farr Company of Los Angeles, California, and is one of a series of different sizes of induction air cleaners designed for internal combustion engines that operate in very dusty locations and for industrial air cleaning.

Figure 1 is a photograph of the test specimen showing the air inlet side with the turbulator vanes of the nine cyclones employed in this model. The specimen was made entirely of steel and was of welded construction without movable or detachable components. The main body of the unit measured 7 1/2 x 7 1/2 x 4 1/2 inches and had a two inch steel pipe attached to the bottom through which the dust that was extracted from the air was removed. The total weight was eight lbs. two oz. The small tube shown at the top of the unit in Figure 1 was installed in this laboratory to observe the vacuum required to withdraw the desired bleed-off air. The manufacturer recommended filtered air flow rates in the range from 135 cfm to 200 cfm and a bleed-off rate of 10 percent of the inlet air flow rate for this size unit.

The Rotonamic device is a cyclonic type air cleaner in which the solid particles are separated from the air by centrifugal force. The dust separating efficiency of such cyclones, therefore, depends to a large extent on the angular speed of the air in the cyclone tube. This circular motion or vortex, is usually produced by turbulator vanes at the tube inlet and the velocity is a function of the pressure drop across these vanes. In order to obtain the same dust separating efficiency in a cyclone of larger diameter the linear air velocity must be increased, requiring a greater pressure drop across the deflecting vanes than for a cyclone of smaller diameter. Except for large stationary installations, where a separate blower could be used to overcome its pressure drop, the cyclone type air cleaner has not previously been considered practical for combustion engines.

Fig. 1

By employing a larger number of small cyclone tubes arranged in parallel instead of using the conventional single large tube the Rotonamic has attained a given angular velocity of the air with a pressure loss better suited to reciprocating combustion engines.

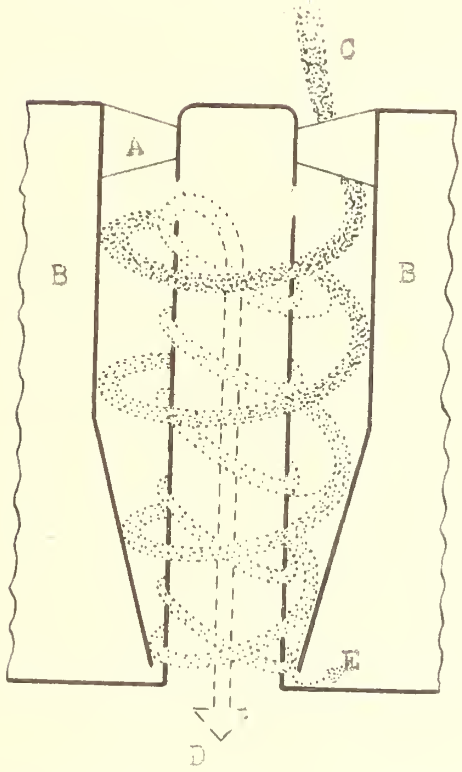
Figure 2 is a schematic drawing of one cyclone tube showing how the inlet air, after the whirling motion is imparted to it by the turbulator vanes, centrifuges the dust against the wall of the outer cylinder. This whirling motion is reported to persist in the entire space between the discharge tube and the outer cylinder with its conical extension. As the axial air velocity decreases near the outer cylinder towards the open end of the cone it is to be expected that there would be a reverse axial flow towards the entering end of the inner cylinder, as shown by the inner spiral in Figure 2, which would augment the dust separating effect of the device. As the dust is centrifuged out of the air it moves along the inside wall of the outer cylinder towards the open end of the cone. The dust concentration at this point has increased to such an extent that it is possible to bleed-off more than 90 percent of the total dust by weight with only 10 percent of the air under certain conditions. The dust-laden bleed-off air from each cyclone flows into the common enclosure which serves as the dust bin and is continuously removed from this space by means of an aspirator installed in the engine exhaust pipe or some other suction device.

3. TEST APPARATUS

For test purposes the filter was clamped tight between two adapters near the middle of a 20 feet length of five inch duct. The edges were sealed with foam rubber strips to prevent outside air leakage. The air was drawn through this duct by an exhaust blower and a second blower was used for withdrawing the dusty bleed-off air. The air flow rates could be adjusted within a wide range by means of valves at the inlets of the two blowers. The air flow rates were measured with orifice flow meters designed in accordance with the A.S.M.E. Research Publication, "Fluid Meters, Their Theory and Application". Each orifice flow meter was equipped with a U-tube manometer and an inclined gage connected in parallel. The

FARR AIR CLEANER "ROTONAMIC".

SCHEMATIC DIAGRAM OF CYCLONE OPERATION.



A DEFLECTING VANES

B DUST BIN

C DUSTY INLET AIR

D FILTERED AIR

E BLEED-OFF AIR

latter was used for small air flow rates and closed off at higher rates when readings were taken on the U-tube manometer.

For each test run a measured amount of dust was placed in a small hopper which fed the groove of a turntable to a constant level. This turntable was mounted on a variable speed Graham transmission and the dust was picked up from the groove by a high pressure aspirator which broke up most of the agglomerations and supplied the dust to the open inlet of the test duct. By changing the speed of the turntable the dust feed rate could be ~~infinitely~~ varied from zero to 30 grams per minute to provide the desired dust concentration.

The dust used was classified air cleaner test dust produced by the A. C. Spark Plug Division of General Motors Corporation. All tests were conducted with a mixture of 50 percent each "fine" and "coarse" dusts. For comparison purposes, two test runs were made with Cottrell percipitate.

The efficiency of the test specimen was determined by sampling the air upstream and downstream of the cleaner with identical sampling nozzles installed in the center of the duct. The velocity of the sampling air at the nozzle inlets was maintained approximately equal to the air velocity in the duct in order to obtain air samples with a representative amount of dust. The dust drawn through the sampling nozzle was collected on glass fiber paper whose smallest fibers were about 0.3 micron in diameter. Tests of the air cleaning efficiency of similar paper by the Atomic Energy Commission indicate that such paper will retain more than 99.99 percent of all particles 0.3 micron and larger and it can, therefore, be considered an absolute filter for these tests.

The air flow rate through the two samplers was measured with identical orifice flow meters which were calibrated with a gas meter. The manometers connected to these flow meters were mounted on either side of a graduated rule to facilitate the adjustments for maintaining equal flow through the two samplers during each test. The filter efficiency was calculated from the formula

$$E_G = (1 - \frac{D}{U}) \times 100\%$$

where E_G = gravimetric efficiency, percent,
D = weight increase of downstream sampler,
U = weight increase of upstream smapler.

Another method was employed for determining the efficiency of the filter based on the discoloration caused by the dust. This method is known as the "National Bureau of Standards Dust-Spot Method" and is described in the paper, "A Test Method for Air Filters" by R. S. Dill, ASHVE Transactions, Vol. 44, p. 339, 1938. In this method, equal air samples from upstream and downstream of the filter are passed through known areas of Whatman #41 filter paper. The areas of the upstream and downstream filter papers are selected by repeated trials to obtain an approximately equal change of light transmission through the upstream and downstream filter papers during a given test while a known amount of dust is fed into the air stream approaching the filter.

4. TEST PROCEDURE AND OBSERVATIONS

The range of air flow rate associated with normal operation of a typical aircraft engine in a helicopter is wider than that recommended by the manufacturer for the Rotonamic air cleaner. Accordingly, the test specimen was operated at filtered air flow rates ranging from 50 cfm to 280 cfm instead of the recommended range from 135 cfm to 200 cfm. A special series of tests was made with 140 cfm filtered air flow rate to determine the effect on the filtering efficiency of varying the bleed-off rate from five percent to 20 percent of the filtered air flow rate.

Table 1 shows a summary of the results at 10 different test conditions with one to three individual tests at each condition. It will be noted that 15.144 grams of dust were introduced into the duct during each test run. Although the dust concentrations ranged from 7.4 to 25.8 mg/cu.ft. during tests 1A, 1B, and 1C there was less than three percent change in the filter efficiency over this range of dust concentrations. Figure 3 shows the efficiency of the test specimen plotted against the filtered air flow rate for both the gravimetric and dust-spot methods. It will be seen that the gravimetric efficiency increased from about 90 percent at 130 cfm air

Table 1 - Summary of Test Results

Farr Rotonamic Air Cleaner with Nine Cyclones

Observed Values	Unit	Test 1A	Test 1B	Test 1C	Test 2A	Test 2B	Test 3A	Test 3B	Test 4A	Test 5A	Test 5B
Filtered Air Flow Rate	CFM	50	50	50	90	90	140	140	140	140	140
Bleed-Off Air Flow Rate	CFM	5	5	5	9	9	7	7	10.5	14	14
Weight of Dust Used, Half coarse, Half Fine	G	15.144	15.144	15.144	15.144	15.144	15.144	15.144	15.144	15.144	15.144
Duration of Test	Min	11.21	10.65	37.13	7.93	6.26	10.73	10.72	6.42	11.78	11.75
Upstream Sampler Wgt Increase	MG	47.0	46.2	45.0	71.2	61.6	66.4	67.9	56.2	73.9	69:6
Downstream Sampler Wgt Increase	MG	14.6	13.5	14.4	9.2	9.1	7.8	7.1	5.1	6.0	7.0
Computed Values											
Inlet Air Flow Rate	CFM	55	55	55	99	99	147	147	150.5	154	154
Inlet Flow Rate Equivalent to 64 Cyclones	CFM	395	395	395	710	710	1070	1070	1070	1070	1070
Bleed-Off in % of Filtered Air Flow	%	10	10	10	10	10	5	5	7.5	10	10
Dust Concentration	MG/Ft^3	24.5	25.8	7.4	19.3	24.4	9.6	9.6	15.7	8.3	8.4
Efficiency - Gravimetric	%	69.0	70.8	68.0	87.1	85.1	88.3	89.5	90.8	91.9	90.0
Average Efficiency - Gravimetric	%	-.	69.2		86.1		88.9		90.8	91.0	
Efficiency - Dust Spot	%	65.5	45.0	53.3	64.4	62.2	60.0	60.3	59.4	65.1	57.0

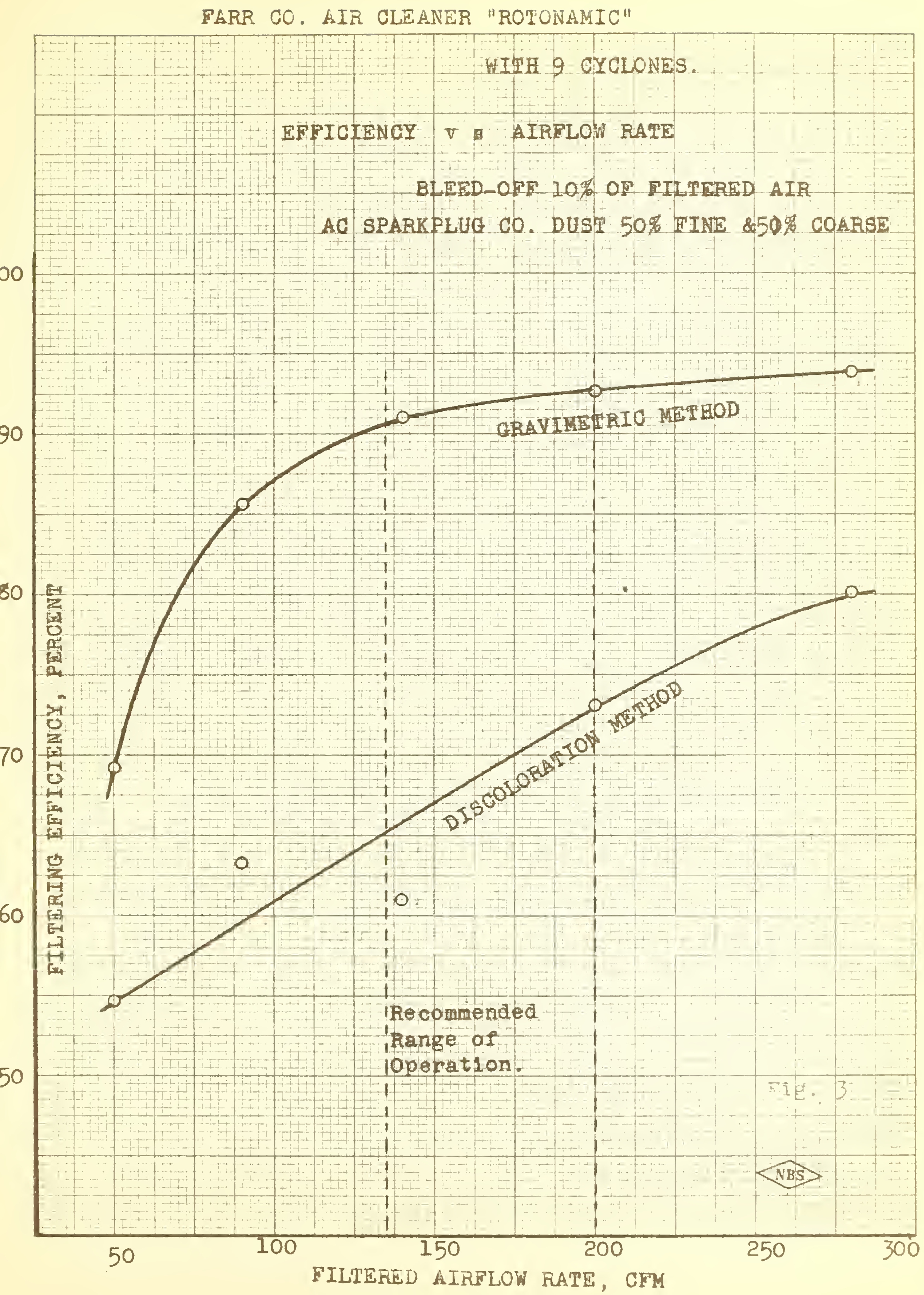
Observed Values	Unit	Test 6A	Test 6B	Test 7A	Test 7B	Test 7C	Test 8A	Test 8B	Test 9A	Test 9B	Test 10A	Test 10B
Filtered Air Flow Rate	CFM	140	140	140	140	140	200	200	280	280	200	200
Bleed-Off Air Flow Rate	CFM	21	21	28	28	28	20	20	28	28	20	20
Weight of Dust Used, Half coarse, Half Fine	G	15.144	15.144	15.144	15.144	15.144	15.144	15.144	15.144	15.144	15.144*	15.144*
Duration of Test	Min	6.32	6.40	9.60	10.83	10.50	6.22	6.15	4.97	4.88	10.17	6.43
Upstream Sampler Wgt Increase	MG	65.8	56.7	58.7	54.2	63.3	87.6	90.7	191.5	81.0	95.3	98.2
Downstream Sampler Wgt Increase	MG	4.0	6.2	2.6	5.0	4.6	7.2	6.0	6.9	7.0	5.2	4.4
Computed Values												
Inlet Air Flow Rate	CFM	161	161	168	168	168	220	220	308	308	220	220
Inlet Flow Rate Equivalent to 64 Cyclones	CFM	1070	1070	1070	1070	1070	1580	1580	2210	2210	1580	1580
Bleed-Off in % of Filtered Air Flow	%	15	15	20	20	20	10	10	10	10	10	10
Dust Concentration	MG/Ft^3	14.9	14.7	9.4	8.3	8.6	11.1	11.2	10.9	11.1	6.8	10.7
Efficiency - Gravimetric	%	93.9	89.1	95.6	90.8	92.7	91.8	93.4	96.3	91.4	94.6	95.5
Average Efficiency - Gravimetric	%	91.5			93.0		92.6		93.9		95.1	
Efficiency - Dust Spot	%	58.0	60.2	66.5	70.9	56.6	74.8	71.3	80.7	79.4	75.7	81.3

*Cottrell Precipitate used as Test Dust

flow rate to about 94 percent at 280 cfm air flow rate in nearly linear relation but dropped rapidly at air flow rates below 130 cfm. The gravimetric efficiency for the range of air flow rates recommended by the manufacturer, 135 cfm to 200 cfm, averaged about 92 percent. The discoloration of dust-spot method showed a nearly linear increase of efficiency from 55 percent at 50 cfm to 80 percent at 280 cfm based on the smooth curve of least mean distances from the plotted points shown in Figure 3. The third significant figure shown for the gravimetric and dust-spot efficiences on Figure 3 and Table 1 is considered uncertain.

The difference in the numerical efficiency values obtained by the gravimetric method and the dust-spot method can be explained qualitatively by the different principles on which the two measurements are based. The gravimetric efficiency is related to the ratio of the weights of dust on the downstream and upstream filter papers, the weight of each particle being proportional to the cube of the effective diameter, and the efficiency is sensitive, therefore, to the capture of large particles. The discoloration efficiency is presumably related to the ratio of the projected areas of all the dust particles on the downstream and upstream filter papers, the projected area of each particle being proportional to the square of the effective diameter. The discoloration efficiency is therefore less sensitive to the capture of large particles than the gravimetric efficiency but more sensitive than a count method. For any air cleaner that is more effective in removing large particles than small ones, the gravimetric efficiency is higher than the dust-spot efficiency. This is illustrated by an example under Discussion and Conclusions.

Test 10, summarized in Table 1, was made with Cottrell precipitate, a dust often used for determining the efficiency of dust filters for heating and ventilating systems. It was found that the average efficiency by the gravimetric method was 95 percent during this test or about 2 1/2 percent higher than it was under the same conditions with A. C. Spark Plug Division dust. The efficiency determined by the dust-spot method, under the same conditions increased about five percent as compared to that with A. C. Spark Plug Co. dust, from 73 percent to 78.5 percent.



FARR CO. AIR CLEANER "ROTONAMIC"
WITH 9 CYCLONES.
EFFICIENCY v s AIRFLOW RATE
BLEED-OFF 10% OF FILTERED AIR
AC SPARKPLUG CO. DUST 50% FINE &50% COARSE
GRAVIMETRIC METHOD
DISCOLORATION METHOD
Recommended
Range of
Operation.
FILTERING EFFICIENCY, PERCENT
FILTERED AIRFLOW RATE, CFM
50
100
150
200
250
300
90
80
70
60
50
NBS

Fig. 3

Table 2

Pressure Loss of Rotonamic Air Cleaner
(Bleed-Off, 10% of Filtered Air Flow)

Filtered Air Flow Rate	Pressure Difference in W.G.	
CFM	Inlet to Outlet	Inlet to Dust Bin
50	0.63	0.20
90	1.69	0.55
140	4.10	1.33
200	8.4	2.57
280	16.9	5.5

Table 2 shows the pressure loss of the Rotonamic air cleaner at different air flow rates. The pressure loss between inlet and outlet for the observed range from 50 cfm to 280 cfm increased from 0.63 inch W.G. to 16.9 inch W.G. and that between inlet and dust bin increased over the same range from 0.20 inch W.G. to 5.5 inch W.G. Figure 4 presents the values in Table 2 graphically and shows the two curves as nearly straight and parallel lines on log-log paper.

Table 3

Effect of Bleed-Off Rate on Filter Efficiency and Bleed-Off Pressure at 140 cfm Filtered Air Flow Rate

Bleed-Off % of Filtered Air	Filter Efficiency, %		Bleed-Off Pressure (Inlet to Dust Bin), In.W.G.
	Gravimetric	Dust-Spot	
5	88.9	60.1	1.00
7.5	90.8	59.4	1.18
10	91.0	61.1	1.26
15	91.5	59.1	1.34
20	93.0	68.7	2.87

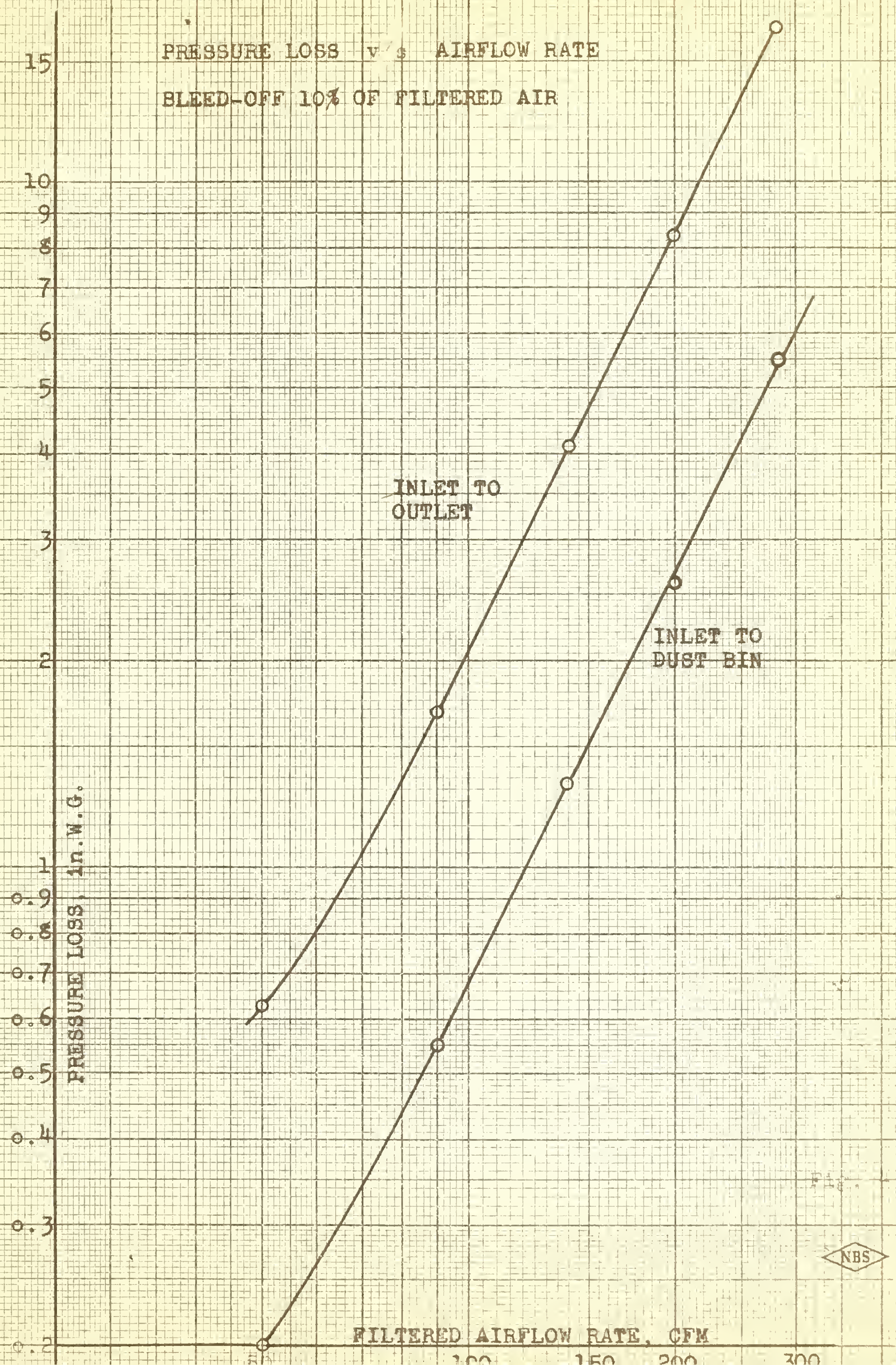

PRESSURE LOSS v/s AIRFLOW RATE
BLEED-OFF 10% OF FILTERED AIR
INLET TO OUTLET
INLET TO DUST BIN
PRESSURE LOSS, in.W.G.
FILTERED AIRFLOW RATE, CFM
15
10
9
8
7
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
100
150
200
300
NBS

Table 3 shows the effect of changing the bleed-off rate at a constant rate of flow of filtered air. The intermediate filtered air flow rate of 140 cfm was selected for this series of tests. The bleed-off rate was varied between 50 percent and 200 percent of its normal rate and the efficiency is shown as determined by both the gravimetric and the dust-spot methods. The values of efficiency observed by the two tests methods bear approximately the same relationship to each other as that indicated by Figure 3. Figure 5 shows the gravimetric efficiency and the bleed-off pressure plotted against the bleed-off rate. The pressure drop from inlet to dust bin was reasonably constant for bleed-off rates from five percent to 15 percent, but increased sharply above a 15 percent bleed-off rate. Under the conditions of the tests the observed gravimetric efficiency increased from 90.8 percent at 7 1/2 percent bleed-off to 91.5 percent at 15 percent bleed-off rate, corresponding to an increase in efficiency of less than 0.1 percent for each one percent increase in bleed-off rate within this range.

Due to a misunderstanding, the 10 percent bleed-off rate used for the evaluation of the test specimen was calculated from the filtered air flow whereas the manufacturer recommended that it be based on the inlet air flow. The 10 percent bleed-off with reference to the filtered air represents only 9.1 percent bleed-off of the inlet air flow. It is evident from Figure 5 that for the range used in these tests one percent change of bleed-off caused less than 0.1 percent change in the efficiency. Therefore, if the test had been conducted with 10 percent bleed-off based on the inlet air instead of the filtered air the gravimetric efficiency values reported in Table 1 would have been higher than those reported by about 0.1 percent.

5. DISCUSSION AND CONCLUSIONS

Important advantages of the Rotonamic air cleaner are that it requires no cleaning, oiling, or servicing and its efficiency remains constant indefinitely for any given duty. The efficiency was found to exceed 90 percent for air flow rates of 125 cfm and above when a bleed-off rate of approximately 10 percent was used. These results were obtained with a half-and-half mixture of classified "coarse" and "fine" test dusts prepared by the A. C.

FARR CO. AIR CLEANER "ROTONAMIC" WITH 9 CYCLONES.

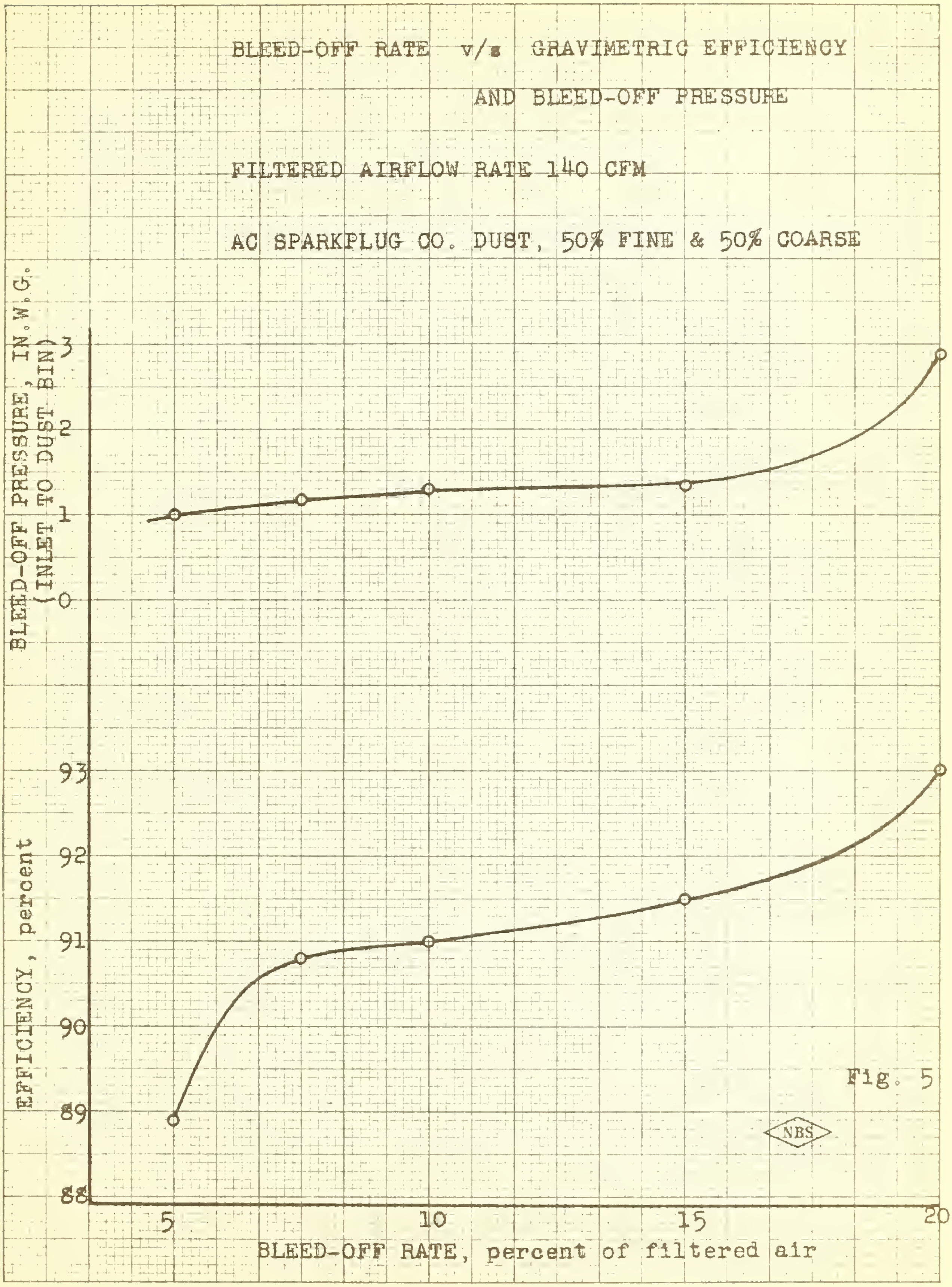


Fig. 5

Spark Plug Division and stated to have the particle size distribution shown below. Presumably, the Rotonamic filter would have a higher efficiency than that observed during these tests with a dust of higher average mass per particle and conversely a lower efficiency with a dust of lower average mass per particle.

Particle Size Distribution of A.C. Spark Plug Division
Coarse and Fine Test Dusts

Coarse Size Range Microns	Coarse Percent	Fine Size Range, Microns	Fine Percent
0 -5	12±2	0 -5	39±2
5 -10	12±3	5 -10	18±3
10 -20	14±3	10 -20	16±3
20 -40	23±3	20 -40	18±3
40 -80	30±3	40 -80	9±3
80 -200	9±3		

The principal disadvantage of the Rotonamic air cleaner is its pressure drop. The pressure drop of the test specimen at the recommended maximum air flow rate of 200 cfm was 8.4 inch W.G. In spite of this high pressure drop it appears likely that the Rotonamic air cleaner can be adapted to helicopter use without exceeding the three percent total power loss usually considered a maximum that can be tolerated for the air cleaning system or device.

Information obtained here on the relation of power loss to absolute pressure reduction at the carburetor intake of reciprocating engines indicates 1 1/2 percent reduction in power for each five inch W.G. reduction in pressure. This corresponds to a 2 1/4 percent reduction in power for a 7.5 inch W.G. pressure drop. The air cleaner under test had an air flow capacity of about 190 cfm for 7.5 inch W.G. pressure drop. Assuming an air induction requirement of 1 1/3 cfm per brake horsepower the test specimen could supply air for an engine with 143 HP under these conditions. If the remaining 3/4 percent of the total of three percent permissible power loss were available for lifting the air cleaning system, the air cleaner and the aspirating device in the exhaust pipe could weigh 10.7 lb. assuming 10 lb. lift per horsepower for the engine. The test specimen alone weighed 8 lbs. 2 oz. made of 16-gage steel. The weight of the test specimen could probably be reduced by half using

aluminum for fabrication thus allowing some margin for the aspirating device required to remove the dust and bleed-off air.

It cannot logically be claimed that either the gravimetric or dust-spot efficiency of an air cleaner is a true measure of the protection it provides to an aircraft engine against wear caused by dust in the induction air. Investigations by Watson, Hanly, and Burchell[1] indicate that the piston ring wear is a constant per unit weight of dust of a given size distribution entering the induction air system for a wide range of concentrations. However, they also found that the wear per unit weight of dust varied with particle size reaching a maximum for particles about 20 microns in diameter and decreasing for either larger or smaller particles. Studies by Pavia[2] at the Australian Aeronautical Research Laboratories led him to conclude that wear at the top of a cylinder and of the top compression rings was proportional to the amount of dust fed into the induction system. He also found that the maximum wear per unit weight of dust occurred with a dust size of about 15 microns. Therefore, an air cleaner that removed particles in the range 10 to 50 microns more efficiently than small ones would presumably be more effective in reducing engine wear than an air cleaner of the same overall efficiency having the same efficiency on all sizes. The Rotonamic air cleaner was of the former type. A microscopic examination of the dust that passed through it revealed that most of the particles were less than three microns in diameter with an occasional 20 to 30 micron particle. The characteristics of the Rotonamic air cleaner with respect to particle size appear to be favorable in view of the above information.

Assuming that the coarse and fine test dusts of the A. C. Spark Plug Division actually had the median size distribution cited earlier in this report, a half- and half mixture of the two kinds would have the size distribution shown below:

1. Abrasive Wear of Piston Rings, by C.E. Watson, F. J. Hanly, and R.W. Burchell, Presented before Annual Meeting of SAE, Jan 1955.
2. An Investigation into Engine Wear Caused by Dusts, by R.W. Pavia, Dept of Supply and Development, Aeronautical Research Laboratory, Melbourne, Australia, 1950

Size Distribution of a Half-and-Half Mixture of A. C. Spark Plug Division Coarse and Fine Test Dusts

Effective Diameter, d Microns	Percent of Total by weight, p
0 -5	25 1/2
5 -10	15
10 -20	15
20 -40	20 1/2
40 -80	19 1/2
80 -200	4 1/2

The gravimetric and dust spot efficiences of an air cleaner can be determined by the following equations if the size distribution of the test dust and the incremental efficiency of the air cleaner for different sizes of dust are known.

$$\text{Gravimetric efficiency} = \frac{e_1p_1 + e_2p_2 + - - - + e_np_n}{100}$$

$$\text{Dust Spot efficiency} = \frac{\frac{e_1p_1}{d_1} + \frac{e_2p_2}{d_2} + - - - + \frac{e_np_n}{d_n}}{\frac{p_1}{d_1} + \frac{p_2}{d_2} + - - - + \frac{p_n}{d_n}}$$

where e_n is the efficiency of the air cleaner for dust particles of the effective diameter d_n, making up p_n percentage of the total weight. The efficiency, e_n, for particles all of the same size would have the same numerical value for the gravimetric, dust-spot, and count methods of measurement.

For illustrative purposes, assume that the Rotonamic air cleaner removed all particles larger than five microns with an efficiency of 100 percent and those from 0-5 microns with a 50 percent efficiency, since the microscopic examination indicated that most of the particles passing through the device were less than three microns in diameter.

On this basis the gravimetric efficiency would be:

$$\frac{(50\times25.5)+(100\times15)+(100\times15)+(100\times20.5)+(100\times19.5)+(100\times4.5)}{100}$$

$$= 87.25\%$$

Assuming all particles of the test dust in a given size range had the mean diameter of the range, the dust-spot efficiency would be:

$$\frac{\frac{50\times25.5}{2.5}+\frac{100\times15}{7.5}+\frac{100\times15}{15}+\frac{100\times20.5}{30}+\frac{100\times19.5}{60}+\frac{100\times4.5}{140}}{\frac{25.5}{2.5}+\frac{15}{7.5}+\frac{15}{15}+\frac{20.5}{30}+\frac{19.5}{60}+\frac{4.5}{140}}$$

$$= 64.2\%$$

This example illustrates the difference that might be expected in the numerical values of the gravimetric and dust-spot efficiences for a particular set of conditions. The relation of the computed values of efficiency shown above for the two methods is very nearly the same as the relation in observed values plotted in Figure 3 for an air flow rate of 100 cfm. However, the theoretical equations shown above do not contain a variable to account for the effect of different air flow rates on the efficiency. Presumably, changing the air flow rate would change the values of e_1, e_2, etc. for particles of selected sizes.

The reduction of wear effected in an engine by the use of an air cleaner can be expressed by the following ratio:

$$\text{Wear Reduction} = \frac{e_1f_1p_1 + e_2f_2p_2 + - - - e_nf_np_n}{f_1p_1 + f_2p_2 + - - - f_np_n}$$

where e_n is the efficiency of the air cleaner for dust particles of the effective diameter d_n making up p_n percentage of the total weight of dust and having a specific wear ratic of f_n in mass of metal worn off per unit mass of dust introduced into a reciprocating engine.

Data on particle size distribution for test dusts can be obtained using the Whitby sedimentation apparatus[3] or other known methods and the report by Watson et al cited above provides information on the relation of wear rate to particle size in a reciprocating engine for Arizona road dust and some other air contaminants. However, no test apparatus has yet been reported for determining the specific efficiencies of an air cleaner for particles of specific size ranges. If information on specific efficiencies were available the wear reduction to be expected from an air cleaner could be determined.

If the data used in the previous example are used in the formula for wear reduction together with the wear factors reported by Watson the wear reduction is shown to be about 96 percent for the air cleaner efficiencies and dust composition assumed. It can be shown that the percentage wear reduction effected by an air cleaner whose efficiency on particles larger than 10 microns is greater than for smaller particles will be greater than the percentage gravimetric efficiency for the A. C. Spark Plug Division test dust and other dusts of similar nature.

3. Measurement of Size Distribution of Small Particles, by K. T. Whitby, ASHAE Journal Section, Heating, Piping and Air Conditioning, Jan 1955.

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to Government Agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the front cover.

Reports and Publications

The results of the Bureau's work take the form of either actual equipment and devices or published papers and reports. Reports are issued to the sponsoring agency of a particular project or program. Published papers appear either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three monthly periodicals, available from the Government Printing Office: The Journal of Research, which presents complete papers reporting technical investigations; the Technical News Bulletin, which presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions, which provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: The Applied Mathematics Series, Circulars, Handbooks, Building Materials and Structures Reports, and Miscellaneous Publications.

Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.25) and its Supplement ($0.75), available from the Superintendent of Documents, Government Printing Office. Inquiries regarding the Bureau's reports and publications should be addressed to the Office of Scientific Publications, National Bureau of Standards, Washington 25, D. C.

NBS